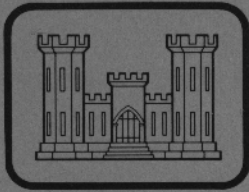
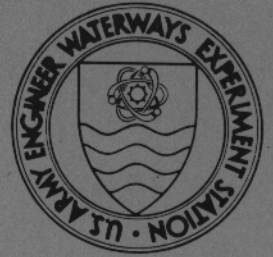


# SYNTHESIS OF RESEARCH RESULTS



## DREDGED MATERIAL RESEARCH PROGRAM



TECHNICAL REPORT DS-78-15

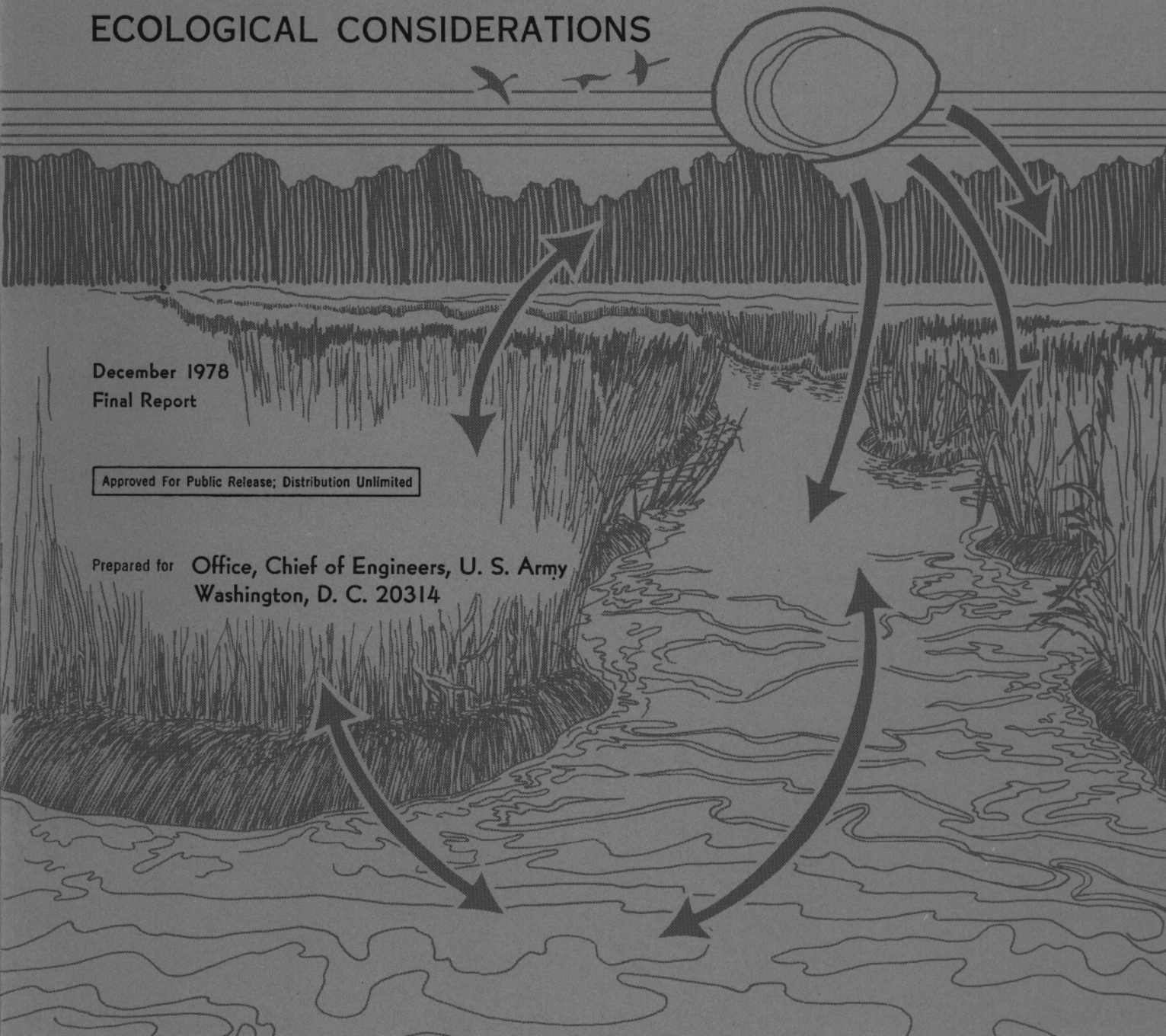
### UPLAND AND WETLAND HABITAT DEVELOPMENT WITH DREDGED MATERIAL: ECOLOGICAL CONSIDERATIONS

December 1978

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for Office, Chief of Engineers, U. S. Army  
Washington, D. C. 20314



## THE DMRP SYNTHESIS REPORT SERIES

Technical Report No.	Title
DS-78-1	Aquatic Dredged Material Disposal Impacts
DS-78-2	Processes Affecting the Fate of Dredged Material
DS-78-3	Predicting and Monitoring Dredged Material Movement
DS-78-4	Water Quality Impacts of Aquatic Dredged Material Disposal (Laboratory Investigations)
DS-78-5	Effects of Dredging and Disposal on Aquatic Organisms
DS-78-6	Evaluation of Dredged Material Pollution Potential
DS-78-7	Confined Disposal Area Effluent and Leachate Control (Laboratory and Field Investigations)
DS-78-8	Disposal Alternatives for Contaminated Dredged Material as a Management Tool to Minimize Adverse Environmental Effects
DS-78-9	Assessment of Low-Ground-Pressure Equipment in Dredged Material Containment Area Operation and Maintenance
DS-78-10	Guidelines for Designing, Operating, and Managing Dredged Material Containment Areas
DS-78-11	Guidelines for Dewatering/Densifying Confined Dredged Material
DS-78-12	Guidelines for Dredged Material Disposal Area Reuse Management
DS-78-13	Prediction and Control of Dredged Material Dispersion Around Dredging and Open-Water Pipeline Disposal Operations
DS-78-14	Treatment of Contaminated Dredged Material
★ DS-78-15	Upland and Wetland Habitat Development with Dredged Material: Ecological Considerations
DS-78-16	Wetland Habitat Development with Dredged Material: Engineering and Plant Propagation
DS-78-17	Upland Habitat Development with Dredged Material: Engineering and Plant Propagation
DS-78-18	Development and Management of Avian Habitat on Dredged Material Islands
DS-78-19	An Introduction to Habitat Development on Dredged Material
DS-78-20	Productive Land Use of Dredged Material Containment Areas: Planning and Implementation Considerations
DS-78-21	Guidance for Land Improvement Using Dredged Material
DS-78-22	Executive Overview and Detailed Summary
DS-78-23	Publication Index and Retrieval System

Destroy this report when no longer needed. Do not return  
it to the originator.

The findings in this report are not to be construed as an official  
Department of the Army position unless so designated  
by other authorized documents.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report DS-78-15	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle)  UPLAND AND WETLAND HABITAT DEVELOPMENT WITH DREDGED MATERIAL: ECOLOGICAL CONSIDERATIONS		5. TYPE OF REPORT & PERIOD COVERED  Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) John D. Lunz Robert J. Diaz Richard A. Cole		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Environmental Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS  DMRP Tasks 4A and 4B
11. CONTROLLING OFFICE NAME AND ADDRESS  Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE December 1978
		13. NUMBER OF PAGES 50
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report)  Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)  Aquatic habitats      Habitats Dredged material      Wetlands Ecology Habitat improvement		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  Regional habitat development and preservation priorities should be established by identifying target populations, groups, or communities and their support populations in an ecosystem context. Properly planned dredged material habitats can be both visually and functionally compatible with preexisting natural habitats. The character of any upland, island, wetland, or aquatic habitat is determined by both physical (geomorphological, hydrological, climatological) and ecological (succession, competition, predation) principles. Properly (Continued)		

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued)

planned disposal operations serve to modify physical conditions and thereby influence (with some predictability) biological responses. Chemically enriched (polluted) dredged material can be used to develop productive fish and wildlife habitats if available information about mechanisms affecting chemical solubilization and biological availability is incorporated into project design.

Consequences of habitat displacement are not easily avoided because of limited understanding about the relative value of various sizes and configurations of specific habitat types. An awareness of existing information describing the value of habitat types to management target resources together with studies designed to clarify specific target population-habitat interactions provides the only insurance against cumulative reduction in fish and wildlife resources. Blanket habitat development policies used in lieu of consideration of the unique qualities of each ecosystem should be avoided.

## PREFACE

This report is designed to provide an ecological framework to assist environmental planners and managers considering the habitat development option of dredged material disposal. The report was prepared as part of the Corps of Engineers' Dredged Material Research Program (DMRP) under the Habitat Development Project (HDP). The DMRP was conducted by the Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., for the Office, Chief of Engineers, U. S. Army.

Mr. John D. Lunz and Drs. Richard A. Cole and Robert J. Diaz (EL) prepared the report under the general supervision of Dr. Hanley K. Smith, Manager, HDP; Dr. Conrad J. Kirby, Chief, Environmental Resources Division; Dr. Roger T. Saucier, Special Assistant for Dredged Material Research; and Dr. John Harrison, Chief, EL. Review of the draft manuscript was provided by Dr. Kenneth O. Allen, U. S. Fish and Wildlife Service; Mr. David Rackley, North Carolina Department of Economic and Natural Resources; and Mr. Michael A. Hardisky and Dr. Robert J. Reimold, Georgia Department of Natural Resources.

This report is also being published as Engineer Manual 1110-2-5018.

COL John L. Cannon, CE, was Director of WES during the preparation of this report. Technical Director was Mr. Fred R. Brown.

## CONTENTS

	<u>Page</u>
PREFACE . . . . .	1
PART I: INTRODUCTION . . . . .	3
PART II: HABITAT DEVELOPMENT BY THE CORPS OF ENGINEERS . . . . .	5
Types of Habitats . . . . .	5
Historical Incidents of Habitat Development . . . . .	6
PART III: MANAGEMENT FROM AN ECOLOGICAL VIEWPOINT . . . . .	8
Management Objective . . . . .	8
Target and Support Populations . . . . .	8
General Considerations for Habitat Management . . . . .	9
PART IV: ANIMAL HABITAT INTERACTIONS IN NATURAL ENVIRONMENTS . .	13
Upland Habitats . . . . .	13
Wetland Habitats . . . . .	18
Aquatic Habitats . . . . .	24
Interactions Among Different Habitats . . . . .	29
PART V: APPLYING ECOLOGICAL PRINCIPLES TO HABITAT DEVELOPMENT TO ACHIEVE MANAGEMENT OBJECTIVES . . . . .	31
Diversification of Habitats . . . . .	31
Development of Upland Habitat . . . . .	31
Development of Wetland Habitat . . . . .	32
Development of Aquatic Habitat . . . . .	34
PART VI: SPECIAL CONSIDERATIONS . . . . .	38
Habitat Displacement . . . . .	38
Chemical Mobilization . . . . .	41
PART VII: CONCLUSIONS AND RECOMMENDATIONS . . . . .	44
REFERENCES . . . . .	46

UPLAND AND WETLAND HABITAT DEVELOPMENT WITH  
DREDGED MATERIAL: ECOLOGICAL CONSIDERATIONS

PART I: INTRODUCTION

1. Habitat development is the consequence of every dredged material disposal operation not specifically designed to prevent the invasion and use of a disposal site by plants and/or animals. Certain individual or groups of plants and animals because of their value to man (commercial, recreational, aesthetic, etc.) may be identified on a local or regional level by resource agencies as targets for management. Understanding how these target plants and animals interact with physical, chemical, and other biological features of their environments should therefore be the basis for directing all dredged material disposal operations where basic trade-offs include habitat preservation and habitat manipulation.

2. This presentation of ecological considerations for habitat development with dredged material is intended to:

- a. Identify the historical precedences for habitat development (Part II).
- b. Describe an ecological management philosophy relevant to habitat development decisions (Part III).
- c. Briefly summarize current ecological theories and observations on natural plant- and animal-habitat interactions (Part IV).
- d. Present some general design considerations for habitat development (Part V).
- e. Consider special conditions that modify dredged material disposal operations designed for habitat development (Part VI).

3. This report is not intended as a catalogue of how-to techniques but provides the basis for reviewing habitat needs during early project planning. The report should bring project planners to the first and most basic information level. The second step is then to evaluate the general feasibility of habitat development according to guidelines presented by Smith (1978). Finally, how-to methods for developing

and/or managing wetland, upland, and island habitats can be found in Environmental Laboratory (1978), Hunt et al. (1978), and Soots and Landin (1978), respectively.



## PART II: HABITAT DEVELOPMENT BY THE CORPS OF ENGINEERS

### Types of Habitats

4. Four different types of habitats will be discussed:

- a. Upland mainlands and peninsulas. Upland mainland and peninsular habitats include vegetated and unvegetated terrestrial areas contiguous with continental land masses.
- b. Upland islands. Vegetated and unvegetated terrestrial areas separated from continental land masses by habitats different from uplands. Island habitats are not necessarily surrounded by open water and, for example, can exist as terrestrial mounds in the midst of marsh. The dominant feature is isolation from adjacent terrestrial areas.
- c. Wetlands. Wetlands typically are recognized as those areas that are inundated or saturated by surface water or groundwater at a magnitude, frequency, and duration sufficient to allow plant associations or communities that tolerate such permanent or periodic inundation or prolonged near-surface soil saturation. Additionally, wetlands include areas without vegetation such as intertidal zones of estuaries, marine coastlines, and shallows of lakes and streams that are subject to periodic inundation.
- d. Aquatic habitats. These habitats include constantly inundated vegetated and unvegetated areas characterized by the lack of emergent vegetation.

5. Natural habitats resist simple categorization schemes useful for environmental planners and managers. Two aspects of habitats are emphasized in these schemes. First, the importance of a given habitat is in the function it serves in a biological system. It is possible for an area to have habitat characteristics that are not functional because potential inhabitants have no access. Examples are an upland pasture that effectively excludes grazing animals or a river containing a water control structure that prevents fish movement. Second, most natural habitats do not function as discrete isolated geographical units but depend upon transfer of matter and energy for structural and functional integrity. A marsh would not persist as a marsh without the association of other aquatic or terrestrial habitats. Regardless of these realities, habitat categorization schemes such as the one presented

above usually describe structure and function of habitats as if they were discrete and separate units.

### Historical Incidents of Habitat Development

6. Incidents of mainland upland, island upland, wetland, and aquatic habitat development have been chronicled by a variety of surveys. Mainland upland habitat has commonly developed as an unplanned result of dredged material disposal. Animal use of vegetated and unvegetated disposal sites has occurred in all regions in the conterminous U. S. Animals most often benefited have been shorebirds, waterfowl, and certain passerine species. Habitats for diverse small mammals (such as rodents and rabbits) and for larger mammals (including beaver and deer) have also developed on dredged material. Over 2000 man-made islands have resulted from dredging in coastal, Great Lakes, and riverine waterways (Soots and Landin 1978). The majority were developed by the disposal of dredged material along the Atlantic and Gulf Intracoastal Waterway Systems during their construction in the 1930's and 1940's. In a recent survey, Garbisch (1977) found projects aimed at developing wetland habitat either completed or under way at 110 Corps District locations, including 70 on the east coast, 18 on the gulf coast, 10 on the west coast, and 12 in the inland areas of the U. S. Incidental development of aquatic habitat has not been well documented although open-water disposal projects have modified existing habitats. Future projects have potential for becoming planned aquatic habitats rather than the unplanned incidental effects of disposal in open water.

7. As is the case for all of the above-mentioned incidents of habitat development, the newly developed habitat is not necessarily more valuable than the replaced habitat. Determining relative habitat value involves additional expense and has rarely been accomplished.

8. More information about habitat construction and function can be found in the reports (Table 1) of aquatic disposal and habitat development field investigations of the Dredged Material Research Program (DMRP).

Table 1

Reports Summarizing Activities at DMRP Habitat Development  
and Aquatic Disposal Field Investigation Sites

<u>Site Name, Location, and Type of Development</u>	<u>Technical Report No.*</u>
<u>Habitat Development Sites</u>	
Windmill Point, James River, Virginia marsh development	D-77-23
Buttermilk Sound, Atlantic Intracoastal Water- way, Georgia, marsh development	D-78-26
Bolivar Peninsula, Galveston Bay, Texas marsh and upland development	D-78-15
Salt Pond No. 3, San Francisco Bay, California marsh development	D-78-57
Apalachicola Bay, Florida, marsh development	D-78-32
Nott Island, Connecticut River, Connecticut upland development	D-78-25
Miller Sands, Columbia River, Oregon marsh and upland development	D-77-38
Port St. Joe, Florida, aquatic development	D-78-33
<u>Aquatic (Open-Water) Disposal Sites</u>	
Eatons Neck, Long Island Sound, New York	D-77-6
Columbia River, Oregon	D-77-30
Ashtabula River, Ohio	D-77-42
Galveston, Texas	D-77-20
Duwamish Waterway, Puget Sound, Washington	D-77-24

---

\* Reports published by the U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 39180.

### PART III: MANAGEMENT FROM AN ECOLOGICAL VIEWPOINT

9. Certain circumstances support the habitat development alternative as a serious dredged material disposal option:

- a. Numerous examples of past deliberate and/or accidental development of valuable habitat.
- b. The feasibility of developing valuable habitat as demonstrated by the DMRP under a variety of dredging and disposal conditions.
- c. Restraints being placed on the aquatic disposal option.

#### Management Objective

10. The first requirement is to define an ecological management objective. The general ecological management objective of habitat development with dredged material would be to maintain or increase the distribution, abundance, and/or biomass of target animal populations and their support populations. Support populations may be plants, animals, or both. The identification of target animal and support populations would occur at a Corps Division or District or other geographic regional level. Ideally, identification would be based on consensus among the Corps and other local, state, and Federal resource agencies.

#### Target and Support Populations

##### Target populations

11. Animal species of direct interest to a habitat development/management plan are targets of that plan. They can be divided into three categories according to their commercial, recreational, or threatened or endangered status. Certain animals, especially aquatic animals including shellfish (e.g., oysters, clams, mussels, blue crabs) and finfish (e.g., striped bass, bluefish, flounder, salmon), fall into both commercial and recreational categories.

##### Support populations

12. Plant and animal species that are used by target animal

populations for cover or food or other purposes are termed ecological support populations. Generally, fish and wildlife management techniques include direct management of target populations by releasing cultivated stock or controlling human use or indirect management by physically manipulating the habitat or altering the density of support populations. With the exception of certain sessile aquatic animals of significant commercial or recreational value (e.g., oysters) and other intensively harvested species such as trout, stocking is often economically impractical and unsuccessful because of mortality or emigration from the stocked area. Plants are most often identified as support populations because in most instances botanical habitats have primary management significance as sources of food and cover for animal populations. For example, traditional values assigned to bottomland hardwood habitats, and more recently to salt marsh and seagrass habitats, are based on their direct or indirect importance to target animal populations. In limited circumstances, perhaps for aesthetic reasons, plants may be the target of habitat development. In properly prepared habitat, plant propagation may enhance successful establishment.

13. Support populations are important because without them target populations may not be attracted to or maintained by an area. Target populations may be attracted to a developed habitat if it is planned around the most important support biota. Most plants and animals can be considered potential support populations. However, a few key species or groups of species usually play a dominant supportive role. Schemes directed toward their management often result in coincidental responses by other less important species. For example, an eelgrass bed may be designed as scallop habitat and for protective cover to blue crabs during molting periods. Coincidentally, algae will develop on the seagrass surfaces, which will provide food to small molluscs and crustaceans which will in turn be fed upon by important finfish species.

#### General Considerations for Habitat Management

14. In most instances, a habitat development project will provide

food (trophic support) or cover (physical or biological structure) critical to the completion of a target animal's life history. A given project could provide both. Once the animal candidate for management has been selected, there are ecological considerations that require some level of evaluation for all life history stages:

- a. Short-term considerations. (1) Food, water, and cover for resting, reproduction, and protection and (2) dependency on adjacent habitats and corridors for movement between habitats.
- b. Long-term considerations: (1) course and time frame of potential changes in soil/sediment and vegetational successional patterns likely to influence the habitat's suitability for the target populations; (2) modification of soil/sediment and vegetational conditions affected by animal use (such as overgrazing); and (3) ability of the habitat and its animal populations to survive potentially frequent natural disturbances including seasonal precipitational and hydraulic extremes and less frequent potential perturbations including severe storms.

15. Examples of how these considerations influence target populations in upland, aquatic, and wetland habitat categories are presented in Part IV. These points suggest the importance of biological and abiological activities that occur outside the boundaries of a habitat development project. Evaluating the long-term considerations is difficult with the currently incomplete understanding of either the natural history or ecology of many potential target populations. However, there are general concepts that have been developed during recent decades that are useful.

#### Thinking at the ecosystem level

16. Any area of nature that includes living organisms and non-living substances interacting to produce an exchange between the living and nonliving parts may be called an ecological system or ecosystem (Odum 1969). In all systems, there is a dynamic balance that has developed through time between components and requires dealing with the ecosystem as a whole (Odum 1969, Copeland 1970, Odum 1977). If habitat development is viewed as a controlled disturbance, it can be placed into an ecosystem perspective using ideas developed by Rhoads et al. (in press) and Odum (1977). Rhoads et al. (in press) summarize the

basic information needed to evaluate the potential success of controlled disturbances as: (a) available species must be related to their position in a successional sequence; (b) seasonal colonization and productive rates must be known; and (c) the tolerance of colonizing species for various degrees of disturbance must be known. With this information, the habitat development plan can be adapted to best fit the ecosystem and human needs, the so-called compromise system of Odum (1969). Although it is not advisable that all ecosystems be of the compromise type, a balance needs to be struck between preservation and exploitation (Figure 1).

#### Habitat development and the physical stability of dredged material

17. Since the habitat development alternative for dredged material disposal may be selected to achieve any of several objectives, it is important to recognize that all of these objectives are not entirely compatible. While a major objective of habitat development may be to prevent the return of dredged material to the navigation channel by providing vegetative cover for erosion control, certain potential target animal populations including some shorebirds may require completely barren habitats, highly susceptible to erosion (Landin 1978). Other species, including waterfowl, may require an intermediate amount of vegetation (such as grasses and herbs), and still other species, such as herons, may require larger shrubs and trees. Among wetland habitats, the choices between a mudflat, sandbar, or marsh would affect animal use patterns and the availability of food and cover to animals, including raccoons, shorebirds, wading birds, waterfowl, and fish. The marsh would provide protection for the small animals feeding within it and stabilization for the substrate against erosion but would provide a less available food resource to the shore and wading birds that probe the unvegetated flats for invertebrate foods. The management choice made for habitat development will affect other uses, including the frequency of maintenance dredging and reuse of the area for disposal.

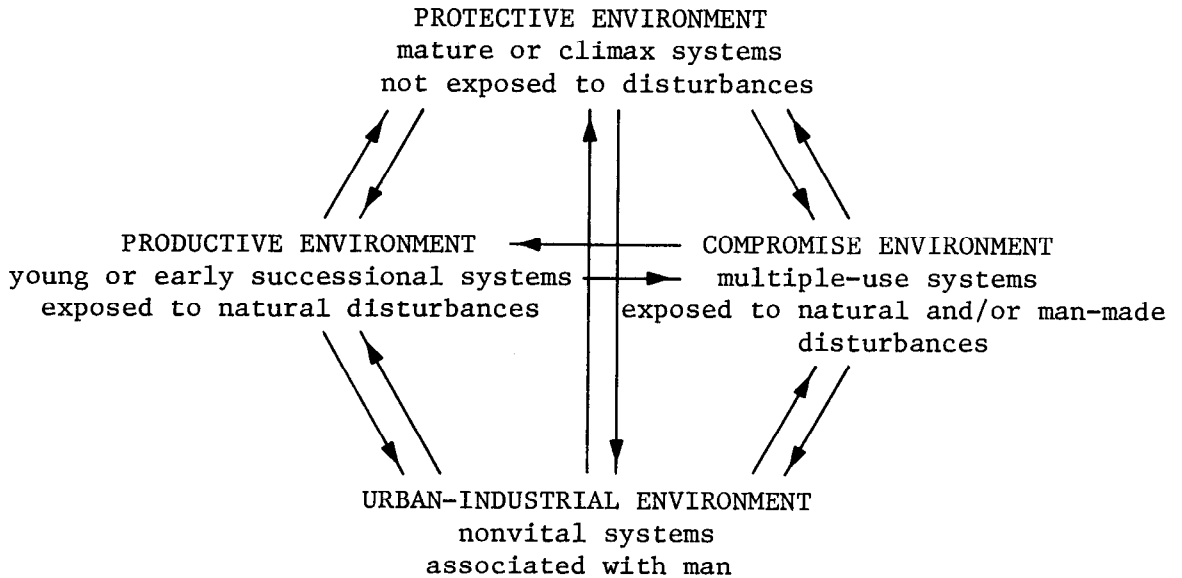


Figure 1. Ecosystem-man interaction model (modified from Odum 1969)

It should be noted that all parts of our ecosystems are interrelated and that a change in one compartment requires balancing changes in the others. Habit development can be viewed as a means of balancing the system, providing protective, productive, or compromise environments where they are needed. Unfortunately, the most difficult problem facing environmental managers is determining the transfer coefficients that determine the flow of energy, materials, and organisms between compartments. An understanding of the flux between compartments and their size and capacity is essential for enlightened habitat management, minimizing the negative aspects of habitat development as described in the text.



## PART IV: ANIMAL HABITAT INTERACTIONS IN NATURAL ENVIRONMENTS

### Upland Habitats

#### Animal-soil relationships

18. In terrestrial environments, many target populations have relatively little direct reliance on the soil substrate, and the soil has relatively little direct influence on the use of the habitat by target populations, except as it affects the amount and kinds of cover and food production. Natural or dredged material substrates by themselves provide cover for a relatively few potential target populations in North America that require it for burrowing or nesting in ground depressions. Among burrowing target populations (primarily beaver, muskrat, otter, and American alligator), none are absolutely dependent on burrows. These animals alternatively require a source of terrestrially or marsh-produced materials for overwintering in dens or nests. Other possible target populations include members of the mink family, rodents, or rabbits, which may use the burrows of other animals. Ground nesters include a number of reptiles and bird species that may be selected as target populations because they are endangered or commercially or recreationally valued. Diamondback terrapins and green, hawksbill, and other sea turtles require well-drained, easily dug soils for egg incubation. A number of potential bird target populations are ground nesters, including most of the shorebirds in the order Charadriiformes, most waterfowl in the family Anatidae, and pelicans, gulls, skimmers, and terns. Most of the shorebirds, gulls, and terns seem to do best in unvegetated barren areas. Most waterfowl usually nest in dense terrestrial herbaceous vegetation, marsh vegetation, or brush and shape their nests from these materials in shallow depressions.

19. The soil factor most important to burrowers is the availability of water-free chambers or nesting depressions. In the case of many waterfowl, turtles, and semiaquatic mammals, the nest depression or burrow chamber must be relatively near water but rarely if ever flooded during the reproductive period. It is imperative for these

animals that some minimal vertical distance of soil substrate above high water be generally maintained during the reproductive period and that some species-specific maximum horizontal distance to the water not be exceeded.

20. Other than in burrowing or ground nesting, the soil plays minor indirect roles. It may be a source of dust for dusting or wallowing, of gravel for bird crops, or of salts for metabolism (Trippensee 1948). In near marine environments, the soil structure may allow the retention of water in small pools for those forms that require water but that are isolated by the sea or long arid distances across land.

21. Some target birds may feed on soil animals, perhaps the most specialized being the woodcock, which feeds on worms in moist soils (Trippensee 1948). Mustelid furbearers like mink may feed partially on grubs, ants, worms, and small burrowing mammals, all of which are associated with the soil (Trippensee 1953). Most of these soil animals are there because of the plant community and its impact on the soil.

22. Target species may derive food or cover directly or indirectly from plants. The more extreme the general climate in the area, the more important the local development of vegetation will be in moderating the microclimate and producing more benign conditions (Drury and Nesbit 1973). Since modification of environmental extremes is likely to reduce the probability of extinction for marginally adapted species, local but intense vegetational management for rare species in such environments may have a profound positive impact on the persistence of a locally threatened or endangered population. This is particularly apparent along some major water courses in arid areas west of the Mississippi River. In those bottomland areas where soil water is locally less limiting than in adjacent uplands, the vegetation can attain a much more structurally developed and diverse successional stage and bring about important microclimatic and edaphic modifications.

#### Plant-animal interactions

23. The plants that invade a new site provide cover and food for animal populations. As a new substrate is invaded by plants and

succeeds toward a more complex community, more species of animals are able to survive, including predators and competitors of target populations. In some cases, successional advance precludes appropriate foods for target species or enables successful predation on, or competition with, the target population. If there is a best successional stage for a species, it is one that provides maximum food and cover for the target species and minimum cover for competitors and predators. Since predators and competitors usually evolve together within communities, the advantages of trying to control competition and predation through control of successional stage will be minor at best.

24. As succession proceeds from earliest to later stages, the vulnerable plant tissue tends to grow out of reach of most target vertebrate herbivores. Some vertebrate species are arboreal and to a degree do use the production of upper strata in forest, but the invertebrates, which are rarely target species, seem more effective in using arboreal leaves than most vertebrate herbivores. Arboreal mammals and birds that might be considered target species for management tend to be granivores or insectivores. The production of seeds and insects makes up a small proportion of the total energy flow through a forest stage because of energy conversion losses incurred during their production. Therefore, vertebrate consumers in woodlands are, in general, less able to produce large biomass than in earlier successional stages where the plants are used by them more effectively.

25. In intermediate successional stages, when woody plants become established, species of vertebrates that browse effectively on parts of the woody plants as well as graze are more inclined to predominate among herbivores. In North America, these mostly include members of the deer family, but relatively few of these animals are totally dependent on woody plants for nutrition. Woody plants seem to be much more important for protective cover from predators or extremes of weather. Vertebrate herbivores in large expanses of forest, particularly dense immature forests, seem to be less productive per unit of plant tissue produced than in earlier successional stages (DeVos 1969). Large herbivores seem to do best in savannah-type communities with

prairie and forest or shrub interspersed.

26. As advanced successional stages of dense forest mature and openings appear scattered throughout (as a result of isolated die-outs of large woody plants and light reaching the soil), the last successional stage tends towards a mosaic of all preceding successional stages with scattered small patches undergoing their own succession within the larger context of the climax plant community. In this stage, vertebrate herbivores tend to be somewhat more abundant than in intermediate forested successional stages but still not nearly as productive as in earlier stages when ground-dwelling carnivores were also more likely to be abundant.

27. In terrestrial ecosystems, large vertebrate populations are intimately associated with a certain plant successional stage or sequential array of closely related stages. To some extent, these larger herbivores and granivores have a direct impact on the plant community because they damage plants when they feed on plant tissues, trample, and otherwise inhibit them or locally favor growth by disseminating nutrients and plant propagules (DeVos 1969). Therefore, they have some measurable impact on the relative abundance and distributions of different plant tissues and the successional stage attained by the plant community.

28. In the long-term and over large areas, terrestrial vertebrates seem not to limit total plant productivity, but they may modify the composition of plant tissues and influence the diversity and relative abundance of plant species. Also, in small, isolated habitats (such as land islands in rivers and in estuaries), there is evidence that herbivorous vertebrates are less likely to be regularly controlled by predation and are more likely to temporarily or permanently devastate the insular plant community, thus causing an overgrazed condition much like that observed on some stocklands (Elton 1958). The overgrazing depresses the carrying capacity of the habitat for the herbivore and forces adjustments in the populations through emigration, death, or depressed birthrates. An obvious example seems to have occurred with a potential target species at Miller Sands, a 40-year-old

island of dredged material in the lower Columbia River which was inhabited by large numbers of nutria. Once nutria were removed by trapping, plant communities responded dramatically with increased primary production and diversity (Clairain et al. 1978). However, the nutria had not been totally effective in retarding succession in the past, because well-developed forest exists on parts of the island. Apparently, even on Miller Sands, where predation on nutria was low, they were not controlling succession. Since dredged material has been periodically deposited on the island over the years, it is possible that edaphic modifications played the primary controlling role. Often, the effect of herbivores is intense for short periods of time and their actual long-term impact on the plant community is relatively minor. Canada geese or other waterfowl are good examples of target populations that may have intense but brief impacts on plant communities; they visit local habitats in large flocks for short periods, feeding on preferred items (Lunz et al. 1978). In the Columbia River, either geese or nutria could be a target species; however, since they compete with each other for food, a choice would have to be made as to which to favor.

29. Other vertebrates are not as mobile as nutria or geese; however, once enough breeding pairs reach an island with plentiful food and little predation, their populations may expand rapidly and affect the plant species composition. Smaller herbivorous mammals fall into this category, especially many species of rodents and rabbits. These animals have high reproductive potentials that may be realized where predation is slack and foods remain available. Small herbivorous mammals can depreciate the value of their plant foods apparently to the point where their health suffers and disease with depressed birth rates causes precipitous drops in population abundances. Even over large mainland areas, small mammal population cycles may fluctuate strongly. Apparently, when predation is not very intense on small isolated insular habitats, predation is much more likely to be out of phase with the population dynamics of herbivores, and fluctuations of herbivores therefore are likely to be even more erratic and more likely to result in local extermination. Because large diverse areas seem to be required for

stabilized populations of large mammalian or avian predators, small islands do not seem to be good habitats to develop for predaceous target populations. Since many of the plants respond to grazing by rapid vegetative growth, productivity may be stimulated with moderate grazing pressures. The grasses particularly fall into this category and, where growing conditions are optimal (such as in tall grass prairies), will quickly form an impenetrable mat of runners and roots that resists establishment of other growth forms. In this case, moderate grazing may help maintain a grass-dominated successional stage for species that require this stage for nesting or food (Yoakum and Dasmann 1969). Where enough water exists in a proper regime on appropriate soils, woody-tissued plants may become established in early successional stages.

30. In summary, it appears that vertebrate herbivores can modify the rate of community succession and somewhat alter the character of plant communities, but over the long run they do not limit rates of primary production or cause major changes in the structural development of the plant community. In fact, the plant community is the major determinant of animal abundance, and the major plant changes seem to be determined by a combination of edaphic and climatic events (Drury and Nesbit 1973). This realization long ago led to reliance on vegetational manipulation as a major tool in wildlife management and investigation into the impact of various practices on the establishment of communities in newly formed environments.

### Wetland Habitats

#### Characteristics of wetland habitats

31. Periodic inundation is the most important characteristic of most wetland habitats affected by Corps activities. For example, periodic tidal and nontidal inundation affects the flow of energy between marshes and aquatic habitats that is the basis for many traditional habitat value statements. The intermittent exposure of the wetland substrates to air and water media is also a source of stress affecting the diversity of wetland communities. Another important

characteristic of wetlands that should be considered for its dual importance in energy flow and as a source of stress is sedimentation. Sedimentation patterns are the result of runoff from terrestrial habitats and transfer of suspended sediment between many wetland and aquatic habitats.

32. Copeland (1970) suggests a classification scheme for coastal ecological systems and subsystems and states that one of the practical aspects of such a classification is predicting responses to disturbances that are related to system types. The classification scheme is based on energy source as modified by natural or man-induced physical or chemical stress or disturbance. Biological diversity and structural complexity tend to increase with increasing energy source input and decreasing disturbance. Organisms living in stable environments put their energies into specialization and diversification; those living in unstable (stressful) environments are adapted to change and tend to be very tolerant, less specialized, and less diverse. This line of thought leads to a conclusion that organisms inhabiting stressful systems are better able to cope with disturbance than those organisms unaccustomed to stressful conditions. According to Copeland (1970), marshes can be classified as temperate, seasonally programmed systems of moderate biological complexity (taxonomic).

#### Animal-substrate relationships

33. Animal populations of wetlands are distributed over and in the sediment and vegetation according to their feeding behavior and needs for protection from predation. When wetland substrates are not covered by water, they serve animals adapted to terrestrial habitats. When the substrates are inundated, they serve animals adapted to aquatic habitats. In a general sense, periodic inundation makes the substrate available to a greater variety of animals and increases the number of potential animal-substrate interactions. Additionally, the transport of marsh vegetation (detritus) to adjacent aquatic habitats provides both substrate and nourishment for aquatic animals (Darnell 1967, Tenore 1977).

34. Energy is either fixed in wetlands by photosynthesis of vascular plants and algae or imported from adjacent aquatic or terrestrial

habitats. The energy is then transferred to aquatic or terrestrial animal populations according to food item availability and feeding adaptations related to animal morphology and behavior. When a wetland is inundated, it supports animals that are largely aquatic in their feeding habits including wading birds, fish-eating birds of prey, certain mammals and reptiles, fish, and a variety of aquatic invertebrates. When the wetland is not inundated, plant and animal foods associated with vegetation or sediment substrates are available to terrestrial animals such as upland mammals and shorebirds. The concept of food availability is important. The periodic inundation characteristic makes food items produced or transported to the wetland habitat available to a diversity of animals that are not necessarily residents of the habitat.

35. The concept of food or cover availability has another aspect related to the location of the marshy areas relative to adjacent habitat types which fill the other life-support functions of animals feeding in the marsh. This other aspect introduces the concept of potential versus actual value of marsh habitats. It is the difference between a marsh island isolated from terrestrial animals that would use food items available in the marsh if they could get to them and a riverine marsh adjacent to a lowland wooded area providing nesting and protective cover for mammals like deer and raccoon, a variety of passerine birds, and birds of prey. A single term describing the difference between potential and actual value might be accessibility, referring to corridors of suitable habitat for movement between different areas.

36. Inventories of animals of the marsh, when supplemented with analysis of the ecological requirements of selected species, provide information about energy utilization and energy flow in the marsh. Target animal populations within commercial, recreational, and rare or endangered categories are primarily associated with marsh habitats through trophic support populations and through requirements for protective cover during periods of their life cycles when they are most vulnerable to predators. Marsh habitats in general terms are most productive of food material supporting the lower end of aquatic food chains (e.g., those animals that feed on plant surfaces or upon detritus and which include numerous insects,



gastropods, crustaceans, and small fish) and the upper end of semiaquatic and terrestrial food chains (e.g., wading birds, waterfowl, birds of prey, racoons, etc.). The structural complexity of marsh habitats resulting from the combination of sediments, live and dead vegetation, and interspersed channels provides cover and camouflage for marsh fauna.

37. Animal residents in wetlands include a diversity of infaunal and epifaunal invertebrates, small fish, amphibians, reptiles, birds, and mammals. With some exceptions, these animals are not unique to marshes and are usually associated with adjacent aquatic bottoms as well. These animals obtain trophic support by feeding upon smaller microbiota, such as bacteria, fungi, and benthic algae, or decomposing particulate organic material originating from land runoff or produced in the marsh (detritus). These animals are in turn eaten by fish or birds feeding in the marsh, or over adjacent unvegetated sand or mudflats, and shallow creek bottoms.

38. Marshes provide food items that, though not unique, are less available to certain animals in other habitats. Shorebirds provide a good example of resource availability: one that is not available during periods of inundation but exploited when exposed. These birds are uniquely adapted by their morphology and feeding behavior to feed in a marsh subunit (e.g., a flat adjacent to or within a marsh habitat). Both light and land runoff energy sources are thereby channeled to the shorebird community via the invertebrate food items.

39. Marshes provide protective cover for animals feeding on the invertebrate infaunal community. Invertebrate infauna that coexist in both marsh and aquatic sediments may be more available to fishes in the constantly inundated aquatic bottom, but fish, especially small fish feeding on that bottom, do so at an energy cost associated with moving between protective cover and a food supply. The physical/structural complexity of the marsh affords the protective cover for small fishes that reside in the marsh. Detrital material resulting from the decomposition of organic material (primarily dead marsh vegetation), appears to be important to a variety of support populations and a few target populations (Tenore 1977).

40. The importance of marshes has most often been reported in units of vascular plant productivity. Statements concerning the value of marshes, especially salt marshes, have been based on the amount of organic biomass produced per unit time in comparisons with natural organic and agricultural systems. The value of primary productivity as an indicator of habitat value will not be resolved here, but some understanding of the relationships between primary productivity and the direct or indirect value of marsh habitats to target animal populations is worth discussion. Vascular plant and nonvascular plant production in marshes is important as both a food resource and as a nonfood cover resource related to the physical/structural complexity mentioned previously. Actual values associated with both of these resource uses are associated with resource availability to target animal populations. The availability of these resources to either terrestrial or aquatic animals is affected by the existence of a pool of animal species capable of exploiting the resource and the existence of access corridors to the resource. Living plant biomass in marsh ecosystems is used directly by animals of the grazing food chain that include invertebrates (like the marsh crab), terrestrial insects (such as leaf hoppers and grasshoppers), fish (such as carp), various species of waterfowl that feed upon plant tissues, and mammals (such as muskrat).

41. The value of detritus has been mentioned above in discussions about the marsh food web. Factors affecting the production and availability of plant detritus include physical energies related to natural inundation, storms, and ice scour and biological energies from grazing. The fragility of a plant affecting its susceptibility to physical damage and the rate of desiccation and physical decomposition is species-specific. Many freshwater marsh plants are more fragile and decompose more quickly than their estuarine and coastal counterparts, which are dominated by the more refractory cordgrass, saltgrass, and needlerush assemblages. Differences in the refractory nature of marsh vegetation are as important within ecosystem types in different regions as they are between ecosystem types in the same region. The needlerush marshes of the gulf coast and South Atlantic regions are less productive of detritus than the cordgrass

marshes in the same coastal ecosystems. Detrital production is related to the turnover (i.e., the number of crops per year and refractory character). Many dominant freshwater marsh plants typically turn over more than once per year, while the more refractory dominant salt marsh plants are often assumed to turn over annually (Kirby and Gosselink 1976). The meaningfulness of any net production figures based on a single peak of growing season estimate needs to be qualified by turnover rate considerations.

42. The availability concept relates to detritus as well as to live plant material. Energy associated with detritus in mature forest habitats is efficiently recycled within that habitat. In much the same fashion, though to a lesser extent, energy fixed in detritus in a high marsh is more often recycled within the marsh than to adjacent habitats (by comparison with detritus produced in low marshes that are more frequently inundated). Gallagher et al. (1977) called this aspect of availability the dispersion of photosynthate. The concept describes the difference between the physical breakdown and transport of northern temperate marsh vegetation by ice scour and the rafting of Spartina alterniflora spp. effected by seasonal tidal extremes in Georgia coastal marshes.

43. The important commercial crustaceans including grass shrimps (Palaemonetes spp.) in the western North Atlantic and penaeid shrimp species on the South Atlantic and gulf coasts are associated with the marsh estuarine habitat complex. Detritus is a food item for both of these species. For these species, coastal estuarine marshes may have dual importance:

- a. As a source of trophic support for animals feeding on detrital material in the marsh and the adjacent aquatic habitat.
- b. As a source of protective cover while feeding in or at the edges of marsh habitats. The importance of this protective function was mentioned before and is manifested in its role as a mechanism of efficient energy utilization.

44. Marshes as habitats providing protective cover may vie in importance with marshes as habitats providing trophic support for

target animal populations. The marsh value literature traditionally refers to marshes as nursery areas for commercially important fisheries. Two investigations that have produced useful information include studies of impounded Louisiana marshes as croaker (Micropogon undulatus) habitat (Clairain 1974) and a New England marsh as habitat for menhaden (Brevoortia tyrannus) (Nixon and Oviatt 1973). Juvenile croakers migrated into the marsh impoundment and resided there for a period of growth, after which they emigrated to gulf coastal waters. Juvenile menhaden are often observed in huge numbers in coastal and estuarian marshes and, based on sheer numbers captured during faunal inventory studies, are usually assigned high importance as a species using the marsh. A physiological study of menhaden conducted as part of a New England marsh ecology study by Nixon and Oviatt (1973) suggests that planktivorous menhaden cannot obtain adequate nutrition in the marsh to fill their trophic life-support requirements even though they can be observed feeding in the marsh. Menhaden appeared to use the marsh as temporary refuge from aquatic predation.

45. In summary, wetland habitats in general and marshes in particular are transitional habitats benefiting target populations most closely associated with upland and aquatic environments. They support floral and faunal populations that function as support populations for important commercial, recreational, and threatened or endangered target populations. The value of marshes as discrete geographic units with unique value to management plans is confounded by the close association of marshes with both upland and aquatic habitat units. Invertebrate populations in wetland habitats are generally similar to those of adjacent aquatic habitats. Their trophic resource value is related to the availability of food resources for birds and mammals specially adapted to feeding in wetlands. Cover provided by the physical structural characteristics of marsh vegetation is perhaps as important to target populations associated with marshes as trophic support.

#### Aquatic Habitats

46. The interactions between target species and aquatic habitats

are by no means simple. The range of spatial complexities offered by the habitat types (beds of submerged aquatic vegetation to homogeneous mud bottoms) along with the lifestyles of the target species (pelagic, epibenthic, or infaunal) allows for a multitude of interactions. All animals are seeking food, space, and/or protection that is provided by the physical and biological structure of the aquatic habitats. Many of the target species, however, at some point in their life history do not directly interact with the structure of a habitat other than in seeking food. This interaction is very important since the objective is to manage target species, but alone it does not give any indication of the interactions between the support populations of target species and the habitat structure that ultimately make the habitat a valuable feeding ground. The remainder of this section will deal with the interactions between support populations of target populations that depend upon a particular aquatic habitat for something other than food and the physical structure of the aquatic habitats.

47. Except for the case of some specific aquatic habitats, such as seagrass beds and oyster reefs, which offer a greater diversity of substrate types, animal-habitat interactions are primarily animal-sediment interactions. Just as important as animal-sediment interactions in structuring the support populations are predation and competition, which are animal-animal interactions. When combined, these interactions of physical and biological factors produce a complex and dynamic system. Any approach to understanding these systems so that habitats can successfully be developed must involve the complex interactions of biological and physical processes occurring within a system.

#### Animal-substrate relationships of the spatially complex habitat

48. This section deals with substrates other than soft bottoms. Substrate here refers to aquatic plants, shell reefs, rocks, or other artificial structures, all of which have in common a higher structural diversity than soft bottoms. The structural diversity of these habitats can harbor a larger diversity of species and in many cases a larger number of individuals than the structurally simpler habitats (Krecker

and Lancaster 1933, Abele 1974, Alfieri 1975, Mackey 1976, Orth 1977). The critical factor pointed out by Abele (1974) is the presence of several different substrates that are differentially used by coexisting species, thus reducing competitive interactions. A species may use one substrate for protection and another as a feeding area.

49. Orth (1977) has shown for various seagrass communities that it is not necessarily the presence of the natural seagrass substrate that is the key to higher diversity of species. In Orth's studies, artificial substrates made of plastic grass managed to attract numbers of species and individuals comparable to those for natural grass substrates in both temperate and tropical areas. Artificial reefs placed on open soft bottom also provide substrate that attracts organisms by providing shelter and food in an otherwise homogeneous environment. Alfieri (1975) documented an increase in biomass of support populations in the immediate area of an artificial reef made from old tires. A variety of potential target species used the reef, including lobster, blue crabs, sculpin, and blackfish.

50. The diversity of support populations is somehow connected with the number of different substrates found in a habitat. The more substrates, the greater the diversity of support populations. This relationship may not hold for all habitats, but Abele (1974) has demonstrated it for marine decapods and MacArthur and MacArthur (1961) for birds.

51. In summary, the most important features to the animal-substrate relation, as defined in this section, are the physical presence of the substrate and its combination with other substrates. Support populations respond positively to the spatial complexity and in turn potentially provide increased trophic support to target species. Even if the target species do not derive trophic support from these habitats, the protection or shelter provided may be even of greater importance in population management.

#### Animal-sediment relationships

52. Sediments in this section include what is generally thought of as soft bottom, usually sand, mud, or some combination of the two

that is not vegetated. By far, most of the aquatic habitats throughout the U. S. fall into this category. There is also a large volume of literature on the subject of animal-sediment relationships in soft bottoms; e.g., Cummins et al. (1966), Johnson and Matheson (1968), Johnson (1971), and Rhoads (1974).

53. The mass properties of the sediment and the effects that biological activities have on the mass properties are the most important factors that mediate the animal-sediment interactions (Rhoads 1970, Rhoads and Young 1970, Thayer 1975). Mass properties of a sediment are all of its physical attributes that give it its character and include such things as grain size, water content, and mineralogy, which affect sediment density, compaction, and theotrophic properties (Boswell 1961). Activity of animals on or in the sediment (bioturbation) can destroy, alter, or create sedimentary structure, thus having a profound effect on the sediments mass properties (Rhoads 1970, Myers 1977a). Bioturbation or sediment processing and sediment reworking includes burrowing, ingestion, and defecation of sediments, tube building, and biodeposition by primarily macrobenthos and mieobenthos (Cummins et al. 1966, Cullen 1973, Rhoads 1974, Myers 1977b). The activities of larger invertebrates and vertebrates, including crabs, lobsters, and fish, tend to be of a larger scale that disrupts the benthos and represents a greater disturbance than bioturbation.

54. It is primarily the macrobenthos and meiobenthos that provide trophic support to target species. Consequently, it is the adaptations of the benthos to life in soft bottoms that are of interest. Soft-bottom sediments are characteristically unstable and prone to periodic disturbance from storm events or shifting sedimentation patterns. Dynamics of bottom sedimentary habitats have caused the animals living in them to respond with a wide variety of mechanisms that can be useful for planning aquatic habitat development. The basic mechanisms include: (a) morphological adaptations (Thayer 1975) for physical support in unstable substrates, and (b) life history patterns (McCall 1977) that permit efficient colonization of disturbed or unstable areas and successional development.

55. The problem of physical support is most critical in

fine-grained muddy sediments with low bulk density. These types of sediments are commonly produced by the hydraulic dredging of fine sediments (Hirsch et al. 1978) and exist in natural fine-textured aquatic habitats afforded protection from wave action. Organisms cope with these soft and unstable substrates by reduced body density, reduced linear dimension, increased surface area per unit volume, and increased buoyancy (Rhoads 1974). These adaptations all aid an organism in maintaining itself near the overlying water column or in the oxygenated sediment layer.

56. Morphological adaptations and other life history characteristics including feeding type, reproductive strategy, and growth pattern will basically determine the ability of a support species to survive in various soft-bottom aquatic habitats. There are two basic groups, with intermediates between the groups, that support species can fit: opportunistic (Grassle and Sanders 1973, Grassle and Grassle 1974) or specialist (MacArthur and Wilson 1967, Grassle and Sanders 1973).

57. Opportunistic species can be characterized as physiological generalists with the ability to capitalize on favorable environmental conditions. They may rapidly increase in abundance by virtue of their high fecundity, short generation, and high intrinsic growth rate (Levinton 1970). Opportunists are adapted to taking advantage of underutilized resources, such as occur after a physical disturbance of the substrate, and are the first species to colonize new or disturbed habitats (McCall 1977). The numerical abundance of opportunists remains high for as long as resources do not become limiting, physical stresses do not exceed adaptive means, biological pressure or competition from nonopportunists or specialized species remains low, and predation losses to target or other species do not exceed replacement rates. The establishment of opportunistic populations is predictable with a fairly high certainty (Virnstein 1977, McCall 1977), but there are times when space and resources will go unused for extended periods (Levinton 1970) for no apparent reasons.

58. Specialist species are, in many ways, the opposite of opportunistic species. Resources are usually limiting to specialist species,



making competition an important part of their community structure. Fecundity and growth rate are lower and generation time longer for specialized species. Environmental stability tends to favor the development of specialist populations (MacArthur 1960, Sanders 1969). The less a substrate changes with time, the more prominent specialist species become.

59. In any particular soft-bottom aquatic habitat, the advantage of opportunistic or specialist or intermediate species will be controlled by the physical stresses that characterize the habitat. At the extremes, there are conditions that favor either a predominance of opportunists or specialists. Usually, over a given habitat, there will be a mixture of populations that can be visualized as a mosaic of both groups and which is dependent upon the recent history of localized disturbances caused by physical or biological agents (Grassle and Sanders 1973, McCall 1977).

#### Interactions Among Different Habitats

60. Just as poorly planned dredging activities have the potential for disrupting natural environments and reducing abundance or biomass in target populations, well-managed dredging may improve upon the yield of these organisms. The control of the arrangements and relative sizes of different habitats will influence animals in numerous ways but most usually as it influences their reproduction, feeding, and refuge.

61. Most semiaquatic reptiles, birds, and mammals valued by man have retained their terrestrial modes of reproduction and require appropriate landforms near their aquatic habitats. Many aquatic animals use shallow shoreline waters for reproduction and feeding. These nearshore areas are often likely to provide the best combination of refuge cover and feeding habitats for many larger forms of semiaquatic and aquatic life. Water depth itself is a major source of cover for many aquatic species, and the proximity of steep drop-offs to food-rich shallows nourished by light and land runoff energy inputs may be crucial for population success. Dredged channels may, in the proper circumstances, act as travel corridors for migratory fish. For species using the surface of the water or nearby land, the vegetational development

provides best refuge from predation and climatic elements. Since the amount of water reaching an area greatly determines the maximum development of standing plant tissue, proximity to soil waters of appropriate qualities and amounts of flooding influences habitat value.

PART V: APPLYING ECOLOGICAL PRINCIPLES TO HABITAT  
DEVELOPMENT TO ACHIEVE MANAGEMENT OBJECTIVES

Diversification of Habitats

62. It is widely believed by ecologists that the occurrence of a diversity of habitat types (increase in spatial diversity) increases the resource value of the entire area to a greater number of species than any one of the individual habitats would (MacArthur 1960, Abele 1974). The environmental planner could combine habitat types to produce a complex of greater value to the ecosystem than a monotonous expanse of similarly developed habitats. Multiple-use aspects of habitat development are also enhanced through the diversity of habitat types.

63. An approach to increasing habitat diversity would be to develop a series or succession of habitat types in the same place. This approach would use time as an integrator of habitat diversity as opposed to developing a variety of habitat types at once. For example, through successive disposal operations a soft-bottom habitat could be first turned into a grass bed, then a wetland, then an island, and finally upland mainland. Careful management would be required for this approach, with constant evaluation of progress toward the final goal and the relative resource value of each step in the sequence.

Development of Upland Habitat

64. The most effective use of dredged material for upland habitat development appears to be in the construction of island or peninsular habitats where target animals can be provided a somewhat isolated breeding opportunity. Good breeding habitats for many target animals are barren and unproductive or too small and isolated to establish a permanent community capable of supporting resident predators. The maintenance costs for these areas may be absorbed in at least two ways: (a) physical permanence and the continued existence of the early, most productive successional stages can be achieved by intensive management for storm

protection and vegetation control, or (b) these areas can be permitted to exist only temporarily, subject to natural erosive forces. The cost would then be computed for their initial construction and projected life without management.

65. Another island habitat type, for certain kinds of avian breeding, should be well developed with shrubs or trees. These islands would need to be larger (several hectares or more) and more permanent than the small barren islands often used by ground nesters, and the soil would need to be more fertile. Propagation of preferred plants may be advised if natural invasion is likely to be slow.

66. Other islands and peninsulas could be managed for waterfowl so that a dense cover of grasses, sedges, and herbs could be maintained. Island size may not be critical so long as the substrates remained permanently above water during the productive season and the islands were isolated by effective predators. Meadows could be developed on relatively large islands or mainlands without diminishing their breeding value as long as a wetland nursery area existed nearby. Good waterfowl breeding habitats would be associated with partially inundated marshy or swampy habitats. The complex of upland and wetland could be designed by constructing islands or peninsular areas with protected lagoonlike embayments, and the arrangement and development of the area would be amenable to long-term, properly timed dredged material disposal operations.

67. Placement of dredged material for mainland habitat development appears less likely to be successful. In situations where a homogeneous plant cover exists, the use of dredged material to develop other successional stages with as much "edge" as possible would probably be the most valuable approach.

#### Development of Wetland Habitat

68. The Habitat Development Project studied the feasibility of constructing marshes with dredged material under a variety of actual field dredging and disposal operational conditions. The results of

short-term observations, usually over two growing seasons following site development, are summarized by Clairain et al. (1978), Lunz et al. (1978), Allen et al. (1978), and Cole (1978). These field studies concluded that, from the physical and vegetational viewpoints, it is possible to develop habitats that are structurally similar to natural habitats. By the end of the 2-year observation period, neither the structure nor the animal use patterns expected in response to that structure had equilibrated, and few conclusions concerning the function of the marsh were possible.

69. The marsh development project at Windmill Point, located in the tidal freshwater reach of the James River, Virginia, and summarized by Lunz et al. (1978), was an exception. The fine-textured dredged material used to develop the Windmill Point site was placed intertidally. Within 6 months following the substrate construction, the site was completely covered with nearly 100 species of plants. Ecological observations were conducted of the plant community, soils, benthos, nekton, and wildlife communities, and comparisons were made between the dredged material and a natural marsh habitat. The Windmill Point study concluded from observations during about a 2-1/2-year period that the experimental or dredged material marsh provided habitat value to resident and transient animal populations equal to or greater than the natural marsh (Virginia Institute of Marine Science 1978). There is no reason for surprise at the outcome of the field studies in marsh habitat development when the nature of channel dredged material is recognized. There is actually nothing artificial about the habitats developed on dredged material; only the methods used for development are artificial.

70. Once the evidence that marshes can be constructed using dredged material is accepted, the issue changes to considering how marsh habitats can be manipulated in dredged ecosystems to best achieve management objectives. Marshes are known to benefit upland, semiaquatic, and aquatic animal populations. Marsh habitats provide great potential for animal-substrate interactions and make efficient use of energy under conditions of optimum association or interspersed with upland and aquatic habitats.

71. Concepts of productivity in marsh systems, when considered in terms of the availability and accessibility of marsh substrates to animal feeding or cover related activities, should be used in planning marsh habitat developments for target populations. If waterfowl are the management target, marshlands providing food and shallow protected waters for young birds existing adjacent to dry upland nesting cover should be constructed. If a fishery is the target, maximum edge and elevation control resulting from the existence of convoluted channels will allow certain important fish populations access to food and cover within marsh vegetation. Variable bathymetry at the mouth of creeks that flood and drain marsh habitats would provide cover and increase feeding efficiency by aquatic predatory animal populations.

72. The elevation of wetlands, including marshes, influences potential ecological value by controlling the quality of the plant community and the availability of marsh substrates to animal populations from adjacent habitats. The control of elevation both within the elevation range populated by a particular ecological support plant species as well as over the range populated by groups of species is crucial in affecting habitat value. Questions about relative values, for example, of a needlerush versus a cordgrass marsh or an arrowhead versus a cattail marsh, would be tabled in terms of support to target populations identified by regional resource planners.

#### Development of Aquatic Habitat

73. Because of associated habitat enhancement aspects, aquatic habitat development has the potential for being the largest application of habitat development from dredged material. The amount of waterway, river, and coastal bottom that is now natural aquatic habitat is enormous and much greater than for any other habitat type. Dredged material might be used to cover and eliminate contaminated sediments from the biologically active zone and allow the area to return to production of potential support populations. The production base of an area might be changed or enhanced through the selective application of dredged

material as a means of changing sediment characteristics (i.e., mud bottom to sand), or providing a fresh supply of nutrient-rich material (i.e., as a thin supply of veneer), or as a controlled periodic disturbance to keep production of support populations high.

74. Care must be taken not to apply one policy or management plan to all aquatic habitats. Aquatic habitats span a wide range of habitats (from submerged aquatic vegetation, to oyster and clam beds, to subtidal soft bottoms) that will react differently to the same treatment. In general, the aquatic habitats most susceptible to a disturbance and difficult to manage would be those that depend upon the presence of a particular species for their integrity, such as wild celery (Vallisneria) or eelgrass (Zostera) beds or oyster reefs. The effective management of these types of aquatic habitats is strongly dependent upon understanding the natural history of the particular species and possibly establishing it as a target population.

75. Conversely, aquatic habitats not dependent upon any particular species, but rather the functioning of a group of species, for its characteristics should be the least sensitive to disturbance or even localized extension. Most soft-bottom areas fit into this category, being well adapted through a diversity of species that are available to perform similar functions, life histories geared to taking advantage of opportunities, and possible genetic selection for types of disturbance. All these characteristics make soft-bottom aquatic habitats most amenable to management.

76. In considering any type of aquatic habitat development, it would be important to analyze the history of the area chosen for development. The long-term or even short-term success of the habitat will depend greatly on past conditions, which will give a good indication of future conditions. For example, a seagrass bed would not be planted in a highly turbid area. The value of the area to be claimed or altered by the aquatic habitat also needs to be considered along with any management plans for the area. This would avoid conflict between the developed habitat's long-term resource value and management objectives for the area. In other words, at what point would it become too ecologically

costly to displace a limiting habitat, such as an oyster reef, with a nonlimiting one, such as open soft bottom built from dredged material?

#### Controlling ecological succession

77. With careful application of the general management objective of habitat development to the overall problem of managing dredged material, it might be possible to enhance the value of a soft-bottom aquatic habitat for target populations. The key to this approach is that the early colonizers of the dredged material need to be important support populations and further that the disposal of dredged material can be used to control succession by acting as a natural disturbance. The disposal of dredged material could be timed to keep densities of support populations high. The ecological principle behind this approach is sound (Sanders 1969, Grassle and Sanders 1973, McCall 1977). Dredged material disposal creates open space and disrupts established communities. Initially, more individuals and species temporarily occupy the disrupted habitat, increasing the value of the habitat to target populations. With time, species interact, and depending on the extent of the habitat modification and the ability of the community to bounce back, the resource value declines as the support populations decline. The cycle could be repeated with the addition of more dredged material at any time. The best interval between disposal would have to be worked out and would depend upon the environment and rate of decline of resource value. This technique of habitat development has promise because unlike other habitat development alternatives, which may require years to develop and reach management objectives after initial construction, its habitat enhancement value is almost immediate and comes from regular disposal of dredged material, allowing the regular reuse of an area.

#### Covering contaminated sediments

78. Areas contaminated by pollutants could be enhanced or possibly returned to their initial ecological state through aquatic habitat development. Areas where contaminants concentrate tend to be depositional, so the potential for successfully covering these contaminated sediments is good as long as the contaminated area itself is not subjected to dredging and water depth is sufficient to allow for the additional sediments.



79. The clean sediments placed on top of the contaminated sediments would then be suitable for colonization by trophically more important support populations and would effectively isolate the contaminants from the environment. Major considerations in applying this form of habitat development would be the porosity of the covering sediments and the ability of the contaminants to migrate to the surface.

80. The management objective for this type of aquatic habitat development would not necessarily be aimed at target or support populations. The need to contain and eliminate contaminants from ecological cycles could be the main objective; the resultant environmental improvement would be an additional benefit.

#### Changing sediment type

81. A change in the sediment type, by providing suitable substrate or trophic support, may be all that is needed to manage for a target species. The texture of surface sediments could be made coarser or finer by mixing with appropriate dredged material to develop the desired habitat.

82. A great deal of caution is needed in exercising this alternative. Particular attention needs to be given to hydraulic and sedimentation patterns that will influence the success of a project by eroding or covering the developed habitat. For example, it is unlikely that a silty habitat development would last long when placed over a wave- or current-influenced sandy area.

## PART VI: SPECIAL CONSIDERATIONS

### Habitat Displacement

83. The displacement of habitat is common to all habitat development projects. The keystone question that needs to be addressed for all projects is: what is the resource value of the new habitat relative to the displaced habitat? Benefits derived from the development of new habitat should not be at the expense of relatively more valuable existing habitat. This logic is reasonable, but the measurement of the resource value of any habitat is very difficult. At present, there is both a lack of information and lack of agreement on the relative resource values of various habitat types to the ecosystem.

84. The lack of information is most obvious. While there is a great deal of production and productivity literature (Kaplan et al. (1974) and Cammen (1976) being examples related to habitat development and dredging), most studies were not conducted to determine resource value. The relative resource value of a marsh habitat development was compared to both preexisting shallow aquatic habitat and a reference marsh by the Virginia Institute of Marine Science (1978) (summarized by Lunz et al. 1978). With ever-increasing emphasis being placed on the value of resources to target populations, information will hopefully accumulate, allowing the development of sound management plans.

85. The lack of agreement as to the relative resource value of various habitats is exemplified by the controversy of the value of marshes to aquatic systems. Darnell (1967), Odum and de la Cruz (1967), Reimold et al. (1975), and others feel that the value of a marsh is the export of marsh plant detritus, while Haines (1977) hypothesizes that, for some systems, terrestrially derived detritus and phytoplankton have greater importance to aquatic systems. The real source value of marshes may lie in their ability to export high-quality energy in the form of target or support populations.

86. Criteria and considerations for evaluation of displaced habitat should follow the same guidelines established for determining the

value of developed habitats. As a management plan evolves around the habitat development alternative, benefits of some sort are expected. Great care must be taken that these easily recognized management benefits are not affected to the detriment of existing habitat that has a higher relative resource value to the ecosystem. The major considerations that need to be addressed in terms of evaluating displaced habitats are:

- a. Accommodation characteristics of the existing habitat.
- b. Extent of existing habitat.
- c. Life span of developed habitat.
- d. Functional aspects of both existing and developed habitats.
- e. External factors influencing target populations.

Accommodation characteristics of existing habitat

87. The impact habitat development will have on an area will depend largely on the accommodation characteristics of the area. The more physically accommodated, or physically stressed, an area is, the less change habitat development activities will have. This statement excludes a change from wetland or aquatic to terrestrial or upland habitat, which completely alters the biological structure of the location. Physically accommodated habitats tend to be productive of a small number of species whose life histories are tuned to exploiting their fluctuating environment.

88. In biologically accommodated areas, those where interactions between organisms play a more important role than physical stress in structuring communities, the disturbance created by the habitat development will be greater and last longer with less certainty as to what the final biological structure will be. A greater variety of organisms inhabit biologically accommodated areas. Their interactions and individual life histories are the uncertainties that may cause the final biological structure to be different than expected.

89. Relating resource value to the accommodation characteristics of habitats would be difficult but necessary in order to assess the applicability of habitat development. For example, if highly biologically accommodated habitats were found to be of higher resource value

than physically or moderately biologically accommodated habitats, then it would be least desirable to develop habitat on the former.

#### Extent of existing habitat

90. If the displaced habitat is limiting in the maintenance or productivity of a potential target animal population, the net result of habitat development could be the establishment of unnecessary habitat for one target population by the destruction of critical limited habitat for another.

91. Unless there is an overwhelming need to provide critical habitat for a particular target population of relatively greater importance (based on regionally established ecological management priorities), it is not reasonable to sacrifice any critical habitat. Examples of limited habitats would be seagrass beds and coral or serpulid reefs, which by virtue of their substrate diversity make them attractive to a wide range of organisms.

#### Life span of developed habitat

92. The entire life span (successional sequence) of a habitat development site needs to be determined and an estimate developed of how long it takes to get from one state (seral stage) to the next. Through succession, the developed habitat may lose its value to target species with time and may eventually have a lesser resource value than the original displaced habitat. If a habitat development site is likely to remain valuable to a target species for only a short period, it might be advisable not to develop the new habitat but instead to opt for the lower but consistent resource value of the existing habitat.

#### Functional aspects of both existing and developed habitats

93. All habitats have both structural and functional aspects. Structure is the most obvious feature when habitat is examined or manipulated in the development of a new habitat type. Functional aspects tend to be cryptic and more difficult to visualize. A habitat development site may look like a marsh but may not be acting like a marsh. Functional aspects can be considered as all the factors that go into making up the resource value of a habitat. For example, wetlands may

function as exporters of high-quality energy in the form of juvenile or adult organisms to the aquatic environment.

94. The functional role of existing habitats must be understood before any program to modify or change them is begun. Similarly, the potential functional role of developed habitats should be perused to ensure that habitat structure will not be developed without habitat function.

#### External factors influencing target populations

95. The impact habitat development actually has in directly enhancing target populations needs critical evaluation in terms of both immediate and long-range responses of target populations. Great care must be taken in comparing the resource value of existing habitats to potential overall impacts that habitat development will have on target populations. It may very well be that factors outside the area of the habitat development are limiting to populations of target species. Newly created habitats would not necessarily have any influence on target populations under these conditions. For example, weather for migration, disease, or hunting pressures outside the habitat development project area may be key factors affecting the abundance of waterfowl populations.

96. The cost of developing habitats that enhance or have no effect on target populations is paid in loss of existing habitat, the cumulative effect of which is unknown. A most difficult question to answer then becomes: when is there enough of a particular habitat for a particular target species? Unfortunately, this question cannot now be answered with certainty for most species. Managers and environmental planners need to evaluate existing scientific information and fill in gaps before habitat development becomes a routine choice of dredged material disposal.

#### Chemical Mobilization

97. The dredging and disposal activity conducted during habitat substrate development produces a potential for acute chemical mobilization that is associated with any upland, wetland, or aquatic disposal

operation. Habitat development identifies the ultimate use of the disposal site as fish and wildlife habitat but does not substantially alter routine dredged material disposal methodologies in most instances.

98. Once the habitat's substrate has been constructed, the long-term opportunity exists for chemical migration from the dredged material to both surface water and groundwater and to target and support populations for which the habitat was designed (Adams et al. 1978, Burks and Engler 1978, Hirsch et al. 1978, Hoeppel et al. 1978).

99. Studies conducted by Gambrell et al. (1977) and Lunz (1978) indicate that the most important factors affecting the long-term mobility and biological availability of metallic and chlorinated hydrocarbon chemicals in dredged material systems that would be produced during habitat development are soil/sediment pH, redox potential (Eh), and soil organic content. Results of these studies provide evidence supporting ideas that total sediment concentrations cannot be used to characterize the pollution potential of dredged material. Generally (there are element-specific exceptions), acidic, oxidized environments with low organic matter concentrations optimize the solubility, mobility, and potential biological availability of metals. Dredged material disposal operations producing substrates that develop environments with these characteristics should be carefully evaluated for habitat development. The disposal of organic, sulfide-rich, fine-grained sediments (typical of protected marine environments) in upland areas produces these conditions. However, when these same sediments are retained in the aquatic environment or placed intertidally for marsh development, the changes in pH and Eh affecting metals solubility do not occur.

100. The Windmill Point marsh development site study (summarized by Lunz et al. 1978) was the only habitat development project conducted under the DMRP with chemically contaminated sediments. The results of a study designed to compare the metallic and chlorinated hydrocarbon levels in marsh soils and plant tissues collected from the dredged material marsh and a natural marsh are reported by Lunz (1978). This study concluded that the soil conditions of primary importance when evaluating the metals uptake potential of marsh plants were Eh, pH, and organic

content. Organic content and, to a lesser extent, pH were important for assessing chlorinated hydrocarbon availability to plants. Differences between the dredged material marsh soil and natural marsh soil chemical concentrations were documented, but they were unrelated to observed plant tissue concentrations. The regulatory trend and the only practical procedure for predicting either short-term or long-term chemical release is in the application of some empirical laboratory testing procedures. The Elutriate Test and bioassay procedures have been developed and are being refined for open-water dredged material disposal operations. Selective sediment extraction procedures such as those successfully used by soil scientists to predict soil fertility are being developed for predicting the availability of dredged material metals to marsh vegetation.

## PART VII: CONCLUSIONS AND RECOMMENDATIONS

101. The main characteristics of upland, island, wetland, and aquatic habitats are determined by a complex interaction of physical (geomorphological, hydrological, climatological) and ecological (succession, competition, predation) principles. The relationship between these principles and habitat development, as a modifying force, is most compatible. When habitat development is dissected into basic parts, it has been shown to be simply an extension or directed enhancement of the physical and ecological principles. Emphasis, however, must be placed on sound planning and clear statement of objectives so as to avoid the development of habitats that are in conflict with their milieu.

102. In at least a cursory sense, an attempt has been made to present the environmental planner with the information needed to understand the principles of habitat development and evaluate the applicability of this alternative as a dredged material disposal option. The management potentials of habitat development are best considered in an ecosystem context. The developed habitats should not only visually fit into the system but must support or provide the functional aspects that are associated with the particular ecosystem.

103. Clear understanding of the importance of habitat to target and support populations cannot be underemphasized. The animal-habitat interaction is a common denominator that will determine the success of developed habitat. Without a balance between needs of target and support populations and the ability of a habitat to provide these needs, the functional aspect of habitat development will not be realized.

104. Habitat development is not without its pitfalls, but careful planning should eliminate most drawbacks. Pollutant mobilization, uptake, and food chain contamination are also of concern. However, with the understanding of the life history of vectors and mechanisms of mobilization and uptake, pollutant transfer and accumulation can be avoided.

105. A not so obvious pitfall of habitat development is the potential for development of unneeded habitat or the displacement of a more valuable habitat with a less valuable habitat. This is a most



difficult problem to resolve. Managers and planners need to know how much of a particular habitat is enough and what are the resource values of different habitat types relative to one another. The state of the art, unfortunately, is not at the point where these problems can easily be answered. Careful evaluation of ecological principles and filling in of information gaps where necessary is the only way to make management decisions that will avoid these problems.

106. The short-term or acute implications of habitat development are most obvious: displacement of existing habitat and possible disruption of surrounding habitat. These effects are unavoidable and are easily factored into the overall management plan. It is the long-term consequences of cumulative habitat displacement that must be addressed. Again, the state of the art is not at a point where this evaluation can easily be made. Only sound ecological management planning will ensure that habitat development, in the long run, is not a possible detriment to the ecosystem.

107. When all factors (physical, ecological, and management) are carefully considered, as presented and discussed in the text, habitat development will most likely be a long-term benefit to the ecosystem. Care must be taken not to make generalized criteria and apply blanket management decisions to all habitat development projects. Each project must be evaluated independently. The various existing habitats that make up ecosystems possess a certain uniqueness that necessitates treatment and management planning at an individual level.

## REFERENCES

- Abele, L. G. 1974. Species diversity of decapod crustaceans in marine habitats. *Ecology*. 55:156-161.
- Adams, D. D., D. A. Darby, and R. J. Young. 1978. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Appendix F: Environmental impacts of marsh development with dredged material: Sediment and water quality. Technical Report D-77-23, Vols I and II. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Alfieri, D. J. 1975. Organismal development on an artificial substrate 1 July 1972 - 6 June 1974. *Estuar. Coast. Mar. Sci.* 3:465-472.
- Allen, H. H., E. J. Clairain, Jr., R. J. Diaz, A. W. Ford, L. J. Hunt, and B. R. Wells. 1978. Habitat development field investigations, Bolivar Peninsula marsh and upland habitat development site, Galveston Bay, Texas; Summary report. Technical Report D-78-15. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Boswell, P. G. H. 1961. Muddy sediments. Adlard and Son, Ltd., Bartholomew Press, Dorking, London.
- Burks, S. A. and R. M. Engler. 1978. Water quality impacts of aquatic dredged material disposal (laboratory investigations). Technical Report DS-78-4. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Cammen, L. M. 1976. Abundance and production of macroinvertebrates from natural and artificially established salt marshes in North Carolina. *American Midl. Natur.* 96:487-493.
- Clairain, E. J., Jr. 1974. Correlations between environmental factors and emigration of juvenile Atlantic croaker (Micropogon undulatus) from a Louisiana marsh nursery. M.S. thesis. Louisiana State University and Agricultural and Mechanical College, Baton Rouge.
- Clairain, E. J., Jr., R. A. Cole, R. J. Diaz, A. W. Ford, R. T. Huffman, L. J. Hunt, and B. R. Wells. 1978. Habitat development field investigations, Miller Sands marsh and upland habitat development site, Columbia River, Oregon; Summary report. Technical Report D-77-38. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Cole, R. A. 1978. Habitat development field investigations, Buttermilk Sound marsh development site, Atlantic Intracoastal Waterway, Georgia; Summary report. Technical Report D-78-26. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Copeland, B. J. 1970. Estuarine classification and responses to disturbance. *Trans. American Fish. Soc.* 99:826-835.
- Cullen, D. J. 1973. Bioturbation of superficial marine sediments by interstitial meiobenthos. *Nature*. 242:323-324.

- Cummins, K. W., C. A. Tryon, and R. T. Hartman. 1966. Organism-substrate relationships in streams. Pymatuning Symposium in Ecology. Univ. of Pittsburgh. 145 pp.
- Darnell, R. M. 1967. Organic detritus in relation to the estuarine ecosystem. Pages 376-381 in G. H. Lauff, ed. Estuaries. American Assoc. Adv. Sci. Pub. 83. Washington, D. C.
- DeVos, A. 1969. Habitat analyses and evaluation. In R. H. Giles, Jr., ed. Wildlife management techniques. 3rd ed. rev. The Wildlife Society, Washington, D. C. 633 pp.
- Drury, W. H. and I. T. Nesbit. 1973. Succession. The Arnold Arboretum J. 54(3):331-368.
- Elton, C. S. 1958. The ecology of invasions by plants and animals. Chapman and Hall, London.
- Environmental Laboratory. 1978. Wetland habitat development with dredged material: Engineering and plant propagation. Technical Report DS-78-16. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Gallagher, J. L., F. G. Plumley, and P. L. Wolf. 1977. Underground biomass dynamics and substrate selective properties of Atlantic coastal salt marsh plants. Technical Report D-77-28. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Gambrell, R. P., V. R. Collard, C. N. Reddy, and W. H. Patrick, Jr. 1977. Trace and toxic metal uptake by marsh plants as affected by Eh, pH, and salinity. Technical Report D-77-40. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Garbisch, E. W., Jr. 1977. Recent and planned marsh establishment work throughout the contiguous United States - A survey and basic guidelines. Contract Report D-77-3. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Grassle, J. F. and H. L. Sanders. 1973. Life histories and the role of disturbance. Deep-Sea Res. 20:643-659.
- Grassle, J. F. and J. P. Grassle. 1974. Opportunistic life histories and genetic systems in marine benthic populations. J. Mar. Res. 32:253-284.
- Haines, E. B. 1977. The origins of detritus in Georgia salt marsh estuaries. Oikos. 29:254-260.
- Hirsch, N. D., L. H. DiSalvo, and R. K. Peddicord. 1978. Effects of dredging and disposal on aquatic organisms. Technical Report DS-78-5. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Hoeppe, R. E., T. E. Myers, and R. M. Engler. 1978. Physical and chemical characterization of dredged material influents and effluents in confined land disposal areas. Technical Report D-78-24. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

- Hunt, L. J., M. C. Landin, A. W. Ford, and B. R. Wells. 1978. Upland habitat development with dredged material: Engineering and plant propagation. Technical Report DS-78-17. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Johnson, R. G. 1971. Animal-sediment relations in shallow water benthic communities. *Marine Geol.* 11:93-194.
- Johnson, M. G. and D. H. Matheson. 1968. Macroinvertebrate communities of the sediments of Hamilton Bay and adjacent Lake Ontario. *Limnol. Oceanogr.* 13:99-111.
- Kaplan, E. H., R. R. Welker, and M. G. Kraus. 1974. Some effects of dredging on populations of macrobenthic organisms. *Fish. Bull.* 72: 445-484.
- Kirby, C. J. and J. G. Gosselink. 1976. Primary production in a Louisiana Gulf Coast Spartina alterniflora marsh. *Ecology.* 57:1052-1059.
- Krecker, F. H. and L. Y. Lancaster. 1933. Bottom shore fauna of western Lake Erie: a population study to a depth of six feet. *Ecology.* 24:79-93.
- Landin, M. C. 1978. National perspective of colonial waterbirds nesting on dredged material islands. In *Proc. 43rd North American Wildlife and Natural Resources Conference*, March 1978. Phoenix, Ariz.
- Levinton, J. S. 1970. The paleoecological significance of opportunistic species. *Lethaia.* 3:69-78.
- Lunz, J. D. 1978. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Appendix E: Environmental impacts of marsh development with dredged material: metals and chlorinated hydrocarbon compounds in marsh soils and vascular plant tissues. Technical Report D-77-23. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Lunz, J. D., T. Zeigler, R. T. Huffman, B. R. Wells, R. J. Diaz, E. J. Clairain, Jr., and L. J. Hunt. 1978. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Summary report. Technical Report D-77-23. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- MacArthur, R. 1960. On the relative abundance of species. *American Natural.* 94:25-36.
- MacArthur, R. H. and J. W. MacArthur. 1961. On bird species diversity. *Ecology.* 42(3):594-598.
- MacArthur, R. H. and E. O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton.
- Mackey, A. P. 1976. Quantitative studies on the Chironomidae (Diptera) of the Rivers Thames and Kennet. II. The Thames Flint Zone. *Arch. Hydrobiol.* 70:310-318.

- McCall, P. L. 1977. Community patterns and adaptive strategies of the infaunal benthos of Long Island Sound. *J. Mar. Res.* 35:221-266.
- Myers, A. C. 1977a. Sediment processing in a marine subtidal sandy bottom community: I. Physical aspects. *J. Mar. Res.* 35(3):609-632.
- Myers, A. C. 1977b. Sediment processing in a marine subtidal sandy bottom community: II. Biological consequences. *J. Mar. Res.* 35(3):633-647.
- Nixon, S. W. and C. A. Oviatt. 1973. Analysis of local variation in the standing crop of S. alterniflora. *Bot. Mar.* 16:103-109.
- Odum, E. P. 1969. The strategy of ecosystem development. *Science*. 164:262-270.
- Odum, E. P. 1977. The emergence of ecology as a new integrative discipline. *Science*. 195:1289-1293.
- Odum, E. P. and A. A. de la Cruz. 1967. Particulate organic detritus in a Georgia salt marsh-estuarine ecosystem. Pages 383-388 in G. H. Lauff, ed. *Estuaries*. American Assoc. Adv. Sci. Pub. 83. Washington, D. C.
- Orth, F. J. 1977. The importance of sediment stability in seagrass communities. Pages 281-300 in B. C. Coull, ed. *Ecology of marine benthos*. Univ. of South Carolina Press, Columbia.
- Reimold, R. J., J. L. Gallagher, R. A. Linthurst, and W. J. Pfeiffer. 1975. Detritus production in coastal Georgia salt marshes. Pages 217-288 in L. E. Cronin, ed. *Estuarine research*. Academic Press, N. Y.
- Rhoads, D. C. and D. K. Young. 1970. The influence of deposit-feeding organisms on sediment stability and community trophic structure. *J. Mar. Res.* 28:150-178.
- Rhoads, D. C. 1970. Mass properties, stability, and ecology of marine muds related to burrowing activity. Pages 381-406 in T. P. Crimes and J. C. Harper, eds. *Trace fossils*. Seel House Press, Liverpool.
- Rhoads, D. C. 1974. Organism-sediment relations on the muddy sea floor. *Oceanogr. Mar. Biol. Ann. Rev.* 12:263-300.
- Rhoads, D. C., P. L. McCall, and J. Yingst. In press. Disturbance and production on the estuarine seafloor. *American Scientist*.
- Sanders, H. L. 1969. Benthic marine diversity and the stability-time hypothesis. Pages 71-81 in *Diversity and stability in ecological systems*. BNL-50175, Brookhaven National Lab., Upton, N. Y.
- Smith, H. K. 1978. An introduction to habitat development on dredged material. Technical Report DS-78-19. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Soots, R. F., Jr. and M. C. Landin. 1978. Development and management of avian habitat on dredged material islands. Technical Report DS-78-18. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

- Tenore, K. R. 1977. Food chain pathways in detrital feeding benthic communities: A review, with new observations on sediment resuspension and detrital recycling. Pages 37-54 in B. C. Coull, ed. Ecology of marine benthos. Univ. of South Carolina Press, Columbia.
- Thayer, C. W. 1975. Morphologic adaptations of benthic invertebrates to soft substrata. J. Mar. Res. 33:177-189.
- Trippensee, R. E. 1948. Wildlife management, Vol I: Upland game and general principles. McGraw-Hill Book Co., New York.
- Trippensee, R. E. 1953. Wildlife management, Vol II: Fur bearers, waterfowl, and fish. McGraw-Hill Book Co., New York.
- Virginia Institute of Marine Science. 1978. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Appendix D: Environmental impacts of marsh development with dredged material: Botany, soils, aquatic biology, and wildlife. Technical Report D-77-23. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
- Virnstien, R. W. 1977. The importance of predation by crabs and fishes on benthic infauna in Chesapeake Bay. Ecology. 58(6):1199-1217.
- Yoakum, J. and W. P. Dasmann. 1969. Habitat manipulation practices. Pages 173-231 in R. H. Giles, Jr., ed. Wildlife management techniques. The Wildlife Society, Washington, D. C.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Lunz, John D

Upland and wetland habitat development with dredged material: ecological considerations / [by John D. Lunz, Robert J. Diaz, Richard A. Cole]. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

50 p. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; DS-78-15)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C.

References: p. 46-50.

1. Aquatic habitats. 2. Dredged material. 3. Ecology.
  4. Habitat improvement. 5. Habitats. 6. Wetlands.
  - I. Diaz, Robert J., joint author. II. Cole, Richard A., joint author. III. United States. Army. Corps of Engineers.
  - IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; DS-78-15.
- TA7.W34 no.DS-78-15